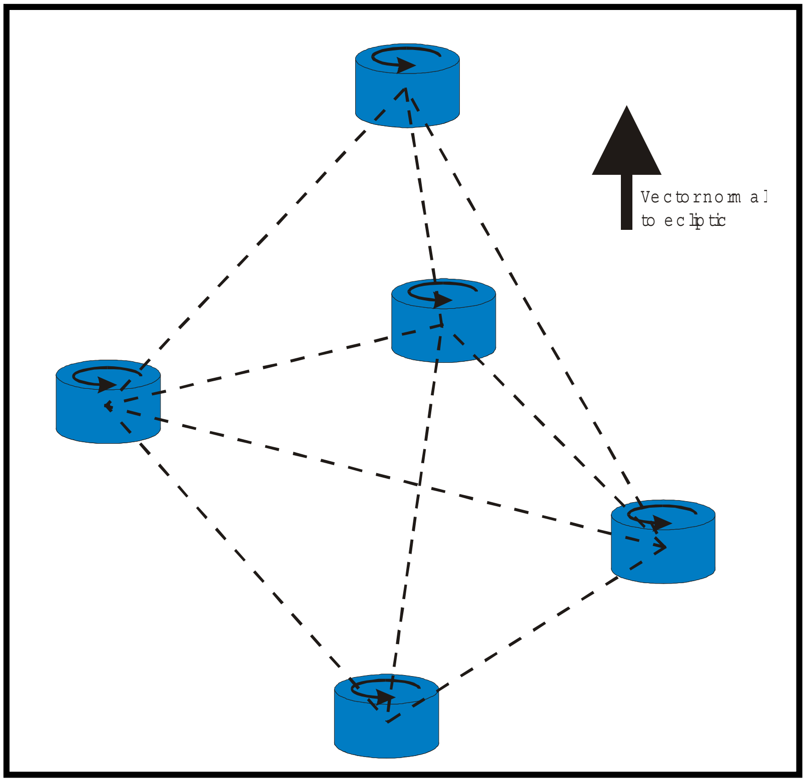
Appendix C

Magnetospheric Multi-Scale Mission

Spacecraft Requirements

1 Introduction

The MMS mission consists of five identically spinning spacecraft acting as a single probe, flying such that a hexahedral configuration like that shown in figure 1 will form at apogee with inter-spacecraft spacing of that configuration varying from less than 10km to several Re throughout the mission life. Each spacecraft will contain an identical set of instruments.



<u>Figure 1 – Hexahedral Configuration</u>

Onboard propulsion will allow the orbits of the MMS "probe" to have four separate mission phases, covering almost the entire magnetosphere, from near-Earth equator to the magnetotail. In each phase the 5-s/c "probe" will dwell at apogee in key boundary regions of magnetic reconnection and energy conversion.

2 Multi-probe Spacecraft

Five identically instrumented spacecraft will comprise the MMS mission.

2.1 Launch vehicle Compatibility

2.1.1 Vehicle

The mission design assumes that all 5 spacecraft will be launched from a single Delta 7925H with a 10' fairing.

2.1.2 Mass to orbit

The Delta 7925H-10 can launch 1540kg to the injection orbit. The PAF mass is not to be included in the 1540kg but what ever structure is needed to stack and individually release the five spacecraft shall be.

2.2 Definition of the orbit

Inclinations are relative to the earth's equator. The orbits and the apogee & perigee distance from the center of the earth are given in units of earth radii.

2.2.1 Phase 0 (launch)

The launch vehicle inserts all 5 spacecraft into a 12Re x 1.2 Re 28.5° orbit. The spacecraft are ejected spinning from the Delta third stage. The time of launch is set so that apogee is approximately at local midnight.

2.2.2 Phase I

The probes change orbit plane to 12Re x 1.2 Re ≤10° orbit. They stay in this orbit for ~~~10~~8 months. The apogee yields long dwell times in the near tail region. The probes initially form a double tetrahedron (hexahedron) with side 10km at apogee. During phase 1 the tetrahedron spacing is increased to 0.1Re.

2.2.3 Phase II

The probes change to 30Re x 1.2Re orbit in stages. The goal is to keep apogee on the dawnside of the magnetopause while raising the apogee from 12 to 30 Re as the magnetic local time changes. The probes form a hexahedron with the sides varing between 0.01 Re to 1 Re. Apogee remains in the midnight side of magnetosphere as the magnetic local time of the apogee changes from ~1000 to ~0400 hours. They stay in this orbit for ~4 months.

2.2.4 Phase III

Phase III Double ~~lunar flyby~~ Lunar Swingby (DLS) changes the orbit inclination to ~90° to the ecliptic. ~~This phase lasts approximately 3 months.~~ Outer loops will be in the magnetotail at approximately 127Re. The tetrahedron spaceing will maximize during this phase at ~1-4Re near apogee to enable studies of plasmoidal structure. Two DLS maneuvers will be performed each lasting approximately one month.

2.2.5 Phase IV

Phase IV changes to 50Re x 10Re polar orbit with apogee in the equatorial plane. In this orbit perigee skims the magnetopause from cusp to cusp.Inclination will be approximately 90° to the ecliptic. They stay in the phase until the consumables are exhausted (expectation is approximately 7 months.)

2.2.6 Summary of Mission Phases

Parameter	Injection/ Separation Phase 0	Phase I	Phase II Apogee follows Magntotail	Phase III Double Lunar Swingby	Phase IV
Orbit (Re)	1.2 x 12	1.2 x 12	1.2 x 30	8 x ~120	10 x 50
Orbit Period	24hr	~24hr(synch ronous)	3.6day	~30day	9.6day
Inclination	28.5°	10° (in magnetic equator)	10°	~~N/A~~0°	90° to ecliptic
Arg of Perigee	0° (daylight)	0°	Apogee 1000 to 0400 hr local time	TBD	0°
Max Ecipse	1hr	1hr	*	*	1.2hr
Eclipses per year	N/A	255	TBD	0°~~TBD~~	4-6
Satellite separation	<10km	10km to 0.1Re	0.01Re to 1Re	1Re to 10Re	10km to 1Re
Phase duration	hours	~0.8 yr	~0.3 yr	~0.25 yr	~0.6 yr

* The mission design and launch time constraints will limit the worst case eclipse duration to < 2hr.

2.2.7 Delta V Budget estimates

Maneuver	**Phase**	**Nominal dV (m/s)**
Inclination change	Separation/Phase 0	326
Spin plane boom deployment	Separation/Phase 0	44
Apogee Adjust	I	277
Apogee Adjust	II	110
Double Lunar Swingby/Phase IV initialization	III	90
Perigee maintenance	I, II, III, IV	48
Launch window/Arg of Perigee adjust	Launch/0	35
Launch dispersion	Launch/0	12
Tetrahedron development	I, II, IV	120
Total		**~~1018~~1062**
Capability		1100
Margin		~~82~~38

2.3 Design Lifetime

The mission science requires the virtual 'sensor' consist of at least 4 spacecraft. The baseline mission architecture consists of 5 spacecraft. This architecture allows for implementation of an aggressive spacecraft design philosophy to maximize design simplicity and minimize redundancy and still ensure meeting science goals. The overarching reliability goal is to have at least 4 spacecraft still operating after the two year mission life time.

The expendables for this mission are to be sized for a dV of at least 1100m/s.

2.4 Spacecraft Attitude Control.

A spin-stabilized spacecraft is assumed with the following parameters:

2.4.1 Spin axis

Spin axis offset from normal to ecliptic plane by 2-5°. Offsetting the spin axis by 2-5° prevents the body of the spacecraft from shadowing the electric field sensors.

2.4.2 Spin rate control

Spin rate controlled to 20rpm (±0.2rpm)

2.4.3 Spin axis knowledge

Spin axis knowledge (post-processed) with respect to inertial space < 0.1°, spin phase knowledge (post-processed) < 0.1°. See also discussion of magnetic field instrument.

2.4.4 Orbit determination:

Knowledge of individual spacecraft position is 100km except immediately prior to maneuvers when the requirement shall be TBDkm (assumed to be significantly smaller than 100km).

2.4.5 Spacecraft stability

The spacecraft shall be stable in all mission phases. Prior to the deployment of the electric field booms the spin-to-tumble inertia ratio shall be > 1.04. The axial and spin plane booms will dominate the dynamics of the spacecraft after deployment, for analysis purposes the axial booms may be assumed to have the properties as described in paragraph 1.4 of the Instrument Specification.

2.4.6 Spacecraft Dynamics

The spacecraft manufacturer shall be responsible for calculating all dynamic interactions between the booms and spacecraft and for ensuring that all coning angle and nutation specifications are met within TBD minutes of eclipse exit and dV maneuvers.

2.5 Electrical Power

Instrument orbit average power is given in the instrument summary section of the MMS Instrument Suite Specification table 1. It is anticipated that extended eclipses will be encountered during phased I, II, III & IV for the MMS spacecraft. A detailed analysis has been performed of eclipse duration throughout these phases. Eclipse duration will be limited to a maximum of 120 minutes and instruments will be assumed to remain powered and operational during eclipses.

It may be assumed that the instruments will work with bus voltages within the range of 22V-35V (nominal 28V).

2.6 Communications

2.6.1 Uplink/Downlink Frequency

The spacecraft shall use an X-band frequency for uplink and downlink.
Command link shall be maintained at maximum apogee.

2.6.2 Groundstation stratagy

Commercial 11m groundstations will be used for phases I & II. DSN 34m High Efficiency (HEF) groundstations will be used for phases III & IV. In order to minimize groundstation cost, the spacecraft shall have the capability to store up to 14days of science data without loss and downlink the data at a rate of at least 1 Mbps but less than 2.2Mbps. The intent is to store data until the range to the groundstation is short enough to allow the data to be transmitted at a high rate.

2.6.3 Spacecraft EIRP

The spacecraft shall be capable of transmitting ~~at least 20dBW~~ an EIRP (Effective Isotropic Radiated Power) of 14dBW in the direction of the earth. The transmitter shall be capable of transmitting continuously for at least 4hours.

2.6.4 Science data/Commanding Volume

The instrument complement will generate ~2 Gbits per day per spacecraft (see table 1 of the instrument Suite Specification.
Commanding for the instruments shall be 100 bytes per instrument per day for each spacecraft.

2.6.5 Tracking

The strategy for tracking the spacecraft and determining their orbit is currently under study. The options being considered are to use two-way Doppler or to require the spacecraft to fly high stability oscillators and use one-way Doppler. Two-way Doppler is the current baseline with a requirement of 100km for normal operations.

2.6.6 Command and Telemetry Format

The uplink and downlink format shall be Consultative Committee for Space Data Systems (CCSDS) Advanced Orbiting Systems (AOS) format.

2.7 Environments

2.7.1 Radiation Environment

The anticipated total radiation dose, without margin, for the MMS mission (all four phases) is shown in Figure 2.

2.7.2 EMC

Since the instruments measure very low levels of plasma energy the spacecraft must not disturb the surrounding plasma. The spacecraft exterior surface shall be an ~~iso~~equi-potential surface with no point of the exterior surface more than 1Volt different than any other point on the spacecraft. This requirement applies to all surfaces including blankets and solar arrays.
The magnetic compatibility requirements are described in Magnetometer instrument section of the MMS Instrument Suite Specification (section 1.5.1)

Figure 2 MMS Total Dose Curve

2.7.3 Contamination

The Hot Plasma instrument and the Energetic Particle instrument are susceptible to particulate contamination and must be under high purity nitrogen purge until launch.

2.8 Mechanical

The spacecraft design shall be compatible with the launch environment for a Delta II 7925H-10 and support the instrument allocations identified in the MMS Instrument Suite Specification. The mechanical design shall ~~accommodate~~ be compatible with the fairing volume, center of gravity location, and stiffness requirements for the Delta II.   The mechanical subsystem shall have provision to provide dedicated high purity nitrogen purge to the Hot Plasma and Energetic Particle instruments of all spacecraft through launch.

The mechanical layout of the instruments and spacecraft shall provide unobstructed fields of view for the Hot Plasma and Energetic Particle instruments.